Egle Tomasi-Gustafsson
DAPNIA/SPhN, CEA/Saclay, 91191 Gif-sur-Yvette Cedex, France

Michail P. Rekalo *
Middle East Technical University, Physics Department, Ankara 06531, Turkey

The purpose of this contribution is to give an outlook of recent results connected with deuteron physics, with electromagnetic and strong interacting probes at intermediate energy. Special attention will be devoted to polarization observables.

I. INTRODUCTION

The deuteron (bound state of proton and neutron) with spin $\mathcal{J}$ and parity P: $\mathcal{J}^P = 1^+$, and with isospin I=0, has been investigated, theoretically and experimentally, since many decades. Few selected problems, which are very actual, will be discussed here according the following plan:

- The knowledge of the deuteron structure, itself, at the largest possible internal momenta (or at the shortest distances between the nucleons). The question which is addressed is the definition of the kinematical region where a description based on nucleons and mesons (basically impulse approximation (IA) with corrections due to meson exchange currents, isobars, relativistic effects..) has to be discarded in favor of a 'high energy view' in terms of quarks and gluons. Here, in particular, pQCD gives predictions concerning the asymptotic behavior of the deuteron form factors and assumes hadron helicity conservation for the amplitudes.

  The transition region between these two regimes should be the privileged domain of intermediate energy machines. High intensity is required by exclusive measurements and/or studies with secondary beams (polarization etc..).

- The deuteron as a probe to investigate the nucleon or the heavy nuclei structure.

  – it can be used to study the properties of the neutron, which is not available as a target;

  – it is an isoscalar probe, which can be very selective in exciting specific states in nucleons and nuclei.

In order to illustrate the different points listed above, we will review some of the last data obtained at Jefferson Laboratory and Saturne. We will show few results from elastic electron-deuteron scattering and proton-deuteron elastic and inelastic scattering. Particular attention will be devoted to polarization observables.

II. THE DEUTERON ELECTROMAGNETIC FORM FACTORS

A. Recent determination of the elastic deuteron electromagnetic form factors

The measurement of the differential cross section of elastic $ed-$scattering, for a fixed value of Q^2, at different scattering angles, allows to determine the structure functions $A(Q^2)$ and $B(Q^2)$:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \cdot \mathcal{S}, \quad \mathcal{S} = A(Q^2) + B(Q^2)\ \tan^2(\theta_e/2)$$

with

$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{\alpha^2\ cos^2(\theta_e/2)E'}{4E^3 sin^4(\theta_e/2)},$$

*Permanent address: *National Science Center KFTI, 310108 Kharkov, Ukraine* where E (E') is the electron beam (the scattered electron) energy and θ_e the electron scattering angle in the Laboratory system. The structure functions A and B can be expressed in terms of the three form factors, G_c (electric), G_m (magnetic) and G_q (quadrupole) as:

$$A(Q^2) = G_c^2(Q^2) + \frac{8}{9}\tau^2 G_Q^2(Q^2) + \frac{2}{3}\tau G_m^2(Q^2), \quad B(Q^2) = \frac{4}{3}(1+\tau)\tau G_m^2(Q^2), \quad \tau = \frac{Q^2}{4M^2},$$

where M is the deuteron mass. In case of unpolarized beam and target the outgoing deuteron is tensorially polarized and the components of the tensor polarization give useful combinations of form factors. In particular t_{20} allows, together with $A(Q^2)$ and $B(Q^2)$, the determination of the three form factors:

$$t_{20} = -\frac{1}{\sqrt{2}\mathcal{S}}\left[\frac{8}{3}\tau G_c G_q + \frac{8}{9}\tau^2 G_Q^2 + \frac{1}{3}\tau\left(1 + 2(1+\tau)\tan^2(\theta_e/2)\right)\right] G_m^2,$$

At the Jefferson Laboratory (JLab), the elastic $ed-$ cross section has been recently precisely measured up to large momentum transfer $Q^2 \simeq 6$ (GeV/c)$^{-2}$, [1,2] and t_{20} has been measured for a momentum transfer up to $Q^2 = 1.9$ (GeV/c)$^{-2}$ [4].

According to [1], the cross sections seems to scale as $(Q^2)^{-10}$, as previously pointed out [3], and predicted by pQCD. However, from the t_{20} data, it clearly appears that the pQCD limit is not yet reached, and that the data follow the trend suggested by IA. On the other hand, it is not possible, from these data, to constrain definitely different models or corrections. For a detailed comparison with theory, see, for example, [1,4].

The question is then, how to proceed further. On the experimental point of view, in the best presently achievable conditions of luminosity, about one month beam time was needed for the the polarization measurement and one week for the cross section at the largest values of Q^2. It seems hard to foresee more favorable experimental conditions, with the present technology related to electron machines. One possibility is to investigate the inelastic deuteron form factors through the reaction $ed \to ed\pi^0$, where for the same momentum transfer for the electron, one acceeds to shortest distances in the deuteron, compared to elastic scattering [5].

In next section we will focus on a conceptual problem, which is the limit of the validity of the assumption of the one photon exchange mechanism in electron-hadron scattering at large momentum transfer. A related problem, that we will not discuss here, is that radiative corrections for polarization effects at large momentum transfer are not known.

B. Beyond the one-photon approximation

The formulas given above are valid if the momentum is transferred from the incident electron to the target by a virtual photon, with the underlying assumption that the possible two-photon contribution is small. The relative contribution of two photon exchange, from simple counting in α, would be of the order of the fine structure constant, $\alpha = \frac{e^2}{4\pi} \simeq \frac{1}{137}$. However, more than 25 years ago it was observed that the relative role of two-photon exchange can increase significantly in the region of high momentum transfer [6–9]. If the transferred momentum is equally shared between two virtual photons, due to the steep decrease of the deuteron form factors, the simple rule of α-counting for the estimation of the relative role of two-photon contribution to the amplitude of elastic $ed-$scattering does not hold anymore. This effect would manifest already at momentum transfer of the order of 1 GeV^2, in particular in the region of diffractive minima.

In Ref. [6] the two-photon amplitude is purely imaginary, at least at small scattering angles, so it cannot interfere with the one-photon exchange amplitude in the differential cross section for unpolarized particles scattering. However, in this case, the polarization observables in elastic $ed-$scattering have to be large, in particular the T-odd polarization observables. But the predicted increasing of the two-photon mechanism is so large that it may be observed even in the differential cross section of elastic $ed-$scattering, at relatively large momentum transfer square, $Q = 8 - 12$ fm^{-1}. An evaluation of this contribution from the existing experimental data has been done in [10].

The crossing symmetry can provide a relation between the matrix elements $\mathcal{M}$ of the the elastic $e^- + h \to e^- + h$ scattering and the e^+e^--annihilation: $e^+ + e^- \to \overline{h} + h$, in one-photon approximation.

$$\overline{|\mathcal{M}(eh \to eh)|^2} = f(s,t) = \overline{|\mathcal{M}(e^+e^- \to \overline{h}h)|^2}. \tag{2.1}$$

The line over $\mathcal{M}$ denotes the sum over the polarizations of all particles (in initial and final states). The Mandelstam variable s is the total energy square and t is the momentum transfer square. They delimit different kinematical regions for the annihilation and the scattering channel.

The presence of a single virtual photon in the reaction $e^+ + e^- \to \gamma^* \to \overline{h} + h$ constrains the total angular momentum $\mathcal{J}$ and the P-parity for the $\overline{h}h-$system to take only one possible value, $\mathcal{J}^P = 1^-$, the quantum number of the photon. In the framework of the one-photon approximation, in the general case, $\overline{|\mathcal{M}(e^+e^- \to h\overline{h})|^2}$ can be written (in CMS) as:

$$\overline{|\mathcal{M}(e^+e^-\to h\overline{h})|^2} = a(t) + b(t)\cos^2\tilde{\theta}, \text{ and } \cos^2\tilde{\theta} = 1 + \frac{\cot^2\frac{\theta_e}{2}}{1+\tau}, \tag{2.2}$$

where $a(t)$ and $b(t)$ are definite quadratic combinations of the electromagnetic form factors for the hadron h and $\tilde{\theta}$ is the angle of the detected hadron.

In case of the presence of 2γ in the intermediate state, in the annihilation channel, any value of the total angular momentum and space parity is allowed, because the relative 3-momentum for the 2γ-state is nonzero, contrary to the case of the one-photon mechanism. The $\overline{h}h$-system, produced through 1γ- and 2γ-exchanges has different values of C-parity, because $C(\gamma) = -1$ and $C(2\gamma) = +1$. Therefore the interference of one- and two-photon contribution must be an **odd** function of $\cos\tilde{\theta}$: $\overline{\mathcal{R}e\mathcal{M}_1\mathcal{M}_2^*} = \cos\tilde{\theta}(a_0 + a_2\cos^2\tilde{\theta} + ...)$.

The SLAC results [3] where obtained at a fixed electron scattering angle. The odd contribution can then be estimated from the cross sections at two angles, for the same Q, one value being given from a fit of the data of ref. [3] and the other by the recent data [1,2]. We can then calculate separately the linear contribution or the cubic contribution in $\cos\tilde{\theta}$. It is expected that deviation from the linear $\cot^2\frac{\theta_e}{2}$ formula would not appear for $Q \leq 5$ fm^{-1}. The resulting ratios C/A and D/A are reported in Fig. 1 and 2 as functions of Q, as open circles [1] and open squares [2]. The data nicely agree: at large momentum transfer these ratios deviate from zero and show a dependence on the transferred momentum, which could result from two photon exchange. However the points had to be rescaled in order to have zero deviation at low Q (corresponding solid symbols) due to systematic errors in the measurement of the cross section between the two sets of data [1] and [2].

While this can not be considered as a definite evidence for the presence of 2γ-exchange in $ed-$elastic scattering, it is the first attempt to obtain a quantitative upper limit of a possible 2γ-contribution, using a parameterization of the $1\gamma \bigotimes 2\gamma$-interference and the existing experimental data.

The 2γ-exchange in elastic hadron scattering can be experimentally searched in different ways: - through the comparison of the cross section for scattering of unpolarized electrons and positrons (by protons or deuterons) in the same kinematical conditions, - looking to the deviation from a straight line on the Rosenbluth plot or measuring specific properties of polarization phenomena: as nonzero $T - odd$ polarization observables, and violation of definite relations between T-even polarization observables and the SF $B(Q^2)$. The measurement of cross section and polarization observables bring complementary and independent pieces of information, as they test the real and imaginary part of the 2γ contribution.

III. THE DEUTERON STRUCTURE FROM *DP* BREAK-UP AND BACKWARD ELASTIC SCATTERING

We showed that the measurement of cross section and analyzing powers in $ed-$elastic scattering allows to determine all the three form factors (in one-photon approximation). These form factors, in IA, are integrals of the wave function over the radial coordinate. On the other hand, the reactions $\vec{d} + p \to \vec{p} + d$ (backward elastic scattering) and $\vec{d} + p \to p + X$ (deuteron break up) are directly related to the deuteron wave functions. In the IA, the tensor analyzing power T_{20} and the polarization transfer κ_0 can be written as:

$$T_{20} = \frac{1}{\sqrt{2}}\frac{\sqrt{8}uw - w^2}{u^2 + w^2},$$

$$\kappa_0 = \frac{u^2 - w^2 - 12uw}{u^2 + w^2},$$

from which one obtains a quadratic relation between T_{20} and κ_0 :

$$\left(T_{20} + \frac{1}{2\sqrt{2}}\right)^2 + \kappa_0^2 = \frac{9}{8}$$

Measurements have been performed at Saturne and Dubna [11,12]. The correlation between the two polarization observables is shown in Fig. 3. The full line is the IA prediction. The two sets of points correspond to backward elastic scattering (open circles) and deuteron break up (solid circles) and they show a very similar behavior. The deviation from IA, which gets larger at larger momenta has been interpreted in different models (see [13] and refs. herein). At this moment it seems fair to conclude that unambiguous signatures of quarks have not yet been found.

A promising way of looking to deuteron at very short distances seems to be the measurement of the tensor analyzing power of pions emitted at 0^0, in the reaction $\vec{d}+p\to\pi+X$, in the cumulative region [14].

IV. THE DEUTERON AS AN ISOSCALAR PROBE

A. The neutron electromagnetic form factors

Having high precision data on the differential cross section for $ed-$ elastic scattering, and assuming a reliable model for their description, one can extract, in principle, the dependence of the electric neutron form factor G_{En} on the momentum transfer Q^2. Such a procedure has been carried out in ref. [15], up to Q^2=0.7 (GeV/c)^2. It can be extended at higher Q^2 using the elastic ed-scattering data mentioned above and recent data on the proton electric form factor [16]. These data have been obtain by the recoil proton polarization measurement in $\vec{e}+p\to e+\vec{p}$, following an idea suggested more than 30 years ago [17] and extend up to Q^2=3.5 (GeV/c)^2. The large sensitivity to the nucleon form factors of the models which describe the light nuclei structure, particularly the deuteron, was already carefully studied in [18], and it was pointed out that the disagreement between the relativistic impulse approximation and the data could be significantly reduced if G_{En} were different from zero.

In the non relativistic IA, the deuteron form factors depend only on the deuteron wave function and on nucleon form factors:

$$G_c=G_{Es}C_E,\quad G_q=G_{Es}C_Q,\quad G_m=\frac{M_d}{M_p}\left(G_{Ms}C_S+\frac{1}{2}G_{Es}C_L\right), \tag{4.1}$$

where M_p is the proton mass, G_{Es}=G_{Ep}+G_{En} and G_{Ms}=G_{Mp}+G_{Mn} are the charge and magnetic isoscalar nucleon form factors, respectively. The terms C_E, C_Q, C_S, and C_L describe the deuteron structure and can be calculated from the deuteron S and D wave functions, $u(r)$ and $w(r)$ [19] :

$$\begin{aligned}
C_E&=\int_0^\infty dr\; j_0\left(\frac{Qr}{2}\right)\left[u^2(r)+w^2(r)\right],\\
C_Q&=\frac{3}{\sqrt{2}\eta}\int_0^\infty dr\; j_2\left(\frac{Qr}{2}\right)\left[u(r)-\frac{w(r)}{\sqrt{8}}\right]w(r),\\
C_S&=\int_0^\infty dr\left[u^2(r)-\frac{1}{2}w^2(r)\right]j_0\left(\frac{Qr}{2}\right)+\frac{1}{2}\left[\sqrt{2}u(r)w(r)+w^2(r)\right]j_2\left(\frac{Qr}{2}\right),\\
C_L&=\frac{3}{2}\int_0^\infty dr\; w^2(r)\left[j_0\left(\frac{Qr}{2}\right)+j_2\left(\frac{Qr}{2}\right)\right],
\end{aligned} \tag{4.2}$$

where $j_0(x)$ and $j_2(x)$ are the spherical Bessel functions. The normalization condition is $\int_0^\infty dr\ \left[u^2(r)+w^2(r)\right]=1$.

With the help of expressions (3) and (4), the formula for $A(Q)^2$, can be inverted into a quadratic equation for G_{Es}. Then G_{Es} is calculated using the experimental values for $A(Q)^2$, assuming, for the magnetic nucleon form factors G_{Mp} and G_{Mn} the usual dipole dependence, which is in agreement with the existing data at a 3% level, up to $Q^2\simeq$ 10 (GeV/c)^2.

In Fig. 4 we illustrate the behavior of the different nucleon electric form factors: G_{Es}, G_{Ep} and G_{En}. The nucleon isoscalar electric form factor, derived from different sets of deuteron data, decreases when Q^2 increases. The solid line represents the Gari-Krümpelmann parametrization [20] for G_{Es}. The dipole behavior, which is generally assumed for the proton electric form factor is shown as a dotted line. The new G_{Ep} data, which decrease faster than the dipole function, are also well reproduced by the Gari-Krümpelmann parametrization (thick dashed line).

The electric neutron form factor can be calculated from the isoscalar nucleon form factor, taking for G_{Ep} a dipole behavior (solid stars) or a fit based on the new data (open stars). The last option leads to values for G_{En} which are in very good agreement with the parametrization [20]. These results shows that the neutron form factor is not going to vanish identically at large momentum transfer, but becomes more sizeable than predicted by other parametrizations, often used in the calculations [15,21] (thin dashed line). Starting from $Q^2 \simeq 2$ (GeV/c)^2 the form factor G_{En} becomes even larger than G_{Ep}. Let us mention that a recent 'direct' measurement [22] at $Q^2 = 0.67$ (GeV/c)^2 finds G_{En}=$0.052 \pm 0.011 \pm 0.005$ in agreement with the present values.

Let us mention that the $\gamma^*\pi^\pm\rho^\mp$-contribution, which is a good approximation for the isoscalar transition $\gamma^* \to \pi^+\pi^-\pi^0$ (γ^* is a virtual photon), is typically considered as the main correction to IA, necessary, in particular, to improve the description of the SF $A(Q^2)$ [3]. However the relative role of MEC is strongly model dependent [23] as the coupling constants for meson-NN-vertexes are not well known and arbitrary form factors are often added [24,25].

It should be pointed out that the $\gamma^*\pi\rho$ vertex is of magnetic nature and its contribution to $A(Q^2)$ has to be of the same order of magnitude as the relativistic corrections.

The forthcoming data about G_{En}, planned at JLab up to Q^2=2 (GeV/c)^2, [26] will be crucial in this respect. The large sensitivity of the deuteron structure to the nucleon form factors shows the necessity to reconsider the role of meson exchange currents in the deuteron physics at large momentum transfer.

B. The nuclear structure

The measurement of polarization transfer for inelastic $\vec{p}$ and $\vec{d}$ scattering by nuclei allows the study of the nuclear response and to disentangle the spin and isospin components. In particular it has been shown that he spin-flip probability is a very good signature of the presence of $\Delta S = 1$ in the continuum, as well as for discrete states. A systematic work has been carried on at LAMPF and at SATURNE, on several nuclei, from ^{12}C to ^{208}Pb. The nuclear response has been measured in different channels and compared to RPA calculations, in order to learn about correlations and collectivity in nuclei [27].

In order to go further, one should complete measurements at very small angles (with a zero degree facility) and with high statistics, and make a multipole analysis in the continuum.

C. The baryon resonances excitation in the inclusive $\vec{d}, p$ scattering

An application of this method based on the measurement of the spin-flip probability, is the study of nucleon resonances, in the reaction $\vec{d} + p \to \vec{d} + X$. The selectivity of reactions such as $p(d,d')X$ or $p(\alpha,\alpha')X$ [28] to the isoscalar part of the N^*-electroexcitation makes these processes complementary to electron-nucleon inelastic scattering, for the study of the N^*-structure. Particular attention has been devoted to the Roper resonance [29] In case of polarized deuteron beam, it has been shown [30] that the ω-exchange model gives a natural and simple description of the polarization phenomena for $\vec{d} + p \to d + X$. The main ingredients of such model are the existing information about the deuteron electromagnetic form factors [32] and the ratio r of the longitudinal and transversal isoscalar cross sections for the excitation of the N^*-resonances [31].

The ω-meson is preferred, among the isoscalar mesons as σ or η, for several reasons. The $\omega NN-$ coupling is large; the ω-meson, being a spin 1 particle, can induce strong polarization effects and an energy-independent cross section. When it is considered as an *isoscalar photon*, then the cross sections and the polarization observables can be calculated from the known electromagnetic properties of the deuteron and N^*, through the vector dominance model.

The tensor analyzing power in $d + p \to d + X$, T_{20}, can be written in terms of the deuteron electromagnetic form factors as:

$$T_{20} = -\sqrt{2}\frac{V_1^2 + (2V_0V_2 + V_2^2)r(t)}{4V_1^2 + (3V_0^2 + V_2^2 + 2V_0V_2)r(t)}, \tag{4.3}$$

where $V_0(t)$, $V_1(t)$ and $V_2(t)$ are linear combinations of the standard electric, G_c, magnetic G_m and quadrupole G_q deuteron form factors. The ratio r characterizes the relative role of longitudinal and transversal isoscalar excitations in the transition $\omega + N \to X$.

From Eq. (5) one can see that all information about the ωNN^*-vertex is contained in the function r only. A zero value of r results in a $t-$ and w-independent value for T_{20}, namely $T_{20} = -1/\sqrt{8}$, for any value of the deuteron electromagnetic form factors. The ratio r is calculated using the collective string model in [31], assuming $SU_{sf}(6)$ symmetry, including the contributions of the following resonances: $N_{11}(1440)$, $S_{11}(1535), D_{13}(1520)$ and $S_{11}(1650)$, which are overlapping in this energy region.

In Fig. 5 we report the theoretical predictions for T_{20}, in framework of ω-model, together with the existing experimental data. In such approximation T_{20} is a universal function of t only, without any dependence on the initial deuteron momentum. The experimental values of T_{20} for $p(\vec{d},d)X$ [33,34], for different momenta of the incident beam are shown as open symbols. These data show a scaling as a function of t, with a small dependence on the incident momentum, in the interval 3.7-9 GeV/c. On the same plot the data for the elastic scattering process $e^-+d\to e^-+d$ [35] are shown (filled stars).

These different data show a very similar behavior: negative values, with a minimum in the region $|t|\simeq 0.35\ GeV^2$ and their value increase toward zero at larger $|t|$. The lines are the result of the ω-exchange model for the $d+p\to d+X$ process: for $r=0$ (dashed-dotted line), the calculation based on [31] for the Roper excitation only is represented by the dotted line and for the excitation of all the four resonances by the the full line. The deuteron electromagnetic form factors have been taken from [32], a calculation based on relativistic impulse approximation, and they reproduce well the $T_{20}-$data for ed elastic scattering [35]. When $r\gg 0$ or if the contribution of the deuteron magnetic form factor $V_1(t)$ is neglected, then T_{20} does not depend on the ratio r, and coincides with t_{20} for the elastic ed-scattering (with the same approximation).

From Fig. 5 it appears that the $t-$behavior of T_{20} is very sensitive to the value of r especially at relatively small r, $r\le 0.5$. The values of r, predicted by model [31], give a very good description of the data, when taking into account the contribution of all four resonances. These data, in any case, exclude a very small value of r, $r\ll 0.1$ as well as very large values of r. Only the Roper resonance has a nonzero isoscalar longitudinal form factor. Without excitation of the Roper resonance, $r=0$, (in the considered kinematical region) and the value for T_{20} becomes $t-$independent: $T_{20}=-1/2\sqrt{2}$, in evident disagreement with existing data.

Due to their specific quark structure, the resonances lying in the concerned mass region, such as $S_{11}(1535)$, $D_{13}(1520)$ and $S_{11}(1650)$, are characterized by a pure isovector nature of longitudinal virtual photons absorbed by the nucleons. The isoscalar longitudinal amplitudes of $S_{11}(1535)$ and $D_{13}(1520)$ electroexcitation vanish due to a specific spin-flavor symmetry, while both isoscalar and isovector longitudinal couplings of $S_{11}(1650), D_{15}(1675)$ and $D_{13}(1700)$ vanish identically.

This behavior of the isoscalar form factors is essential for the correct description of the existing experimental data on the $t-$dependence of T_{20} for the process $d+p\to d+X$.

One could improve the model taking into account for example, other meson exchanges, or the effects of the strong interaction in initial and final states. However these corrections are strongly model- and parameter- dependent and the existing experimental data are not good enough to constrain the additional parameters which have to be added.

The successful description of the polarization observable T_{20} can be considered as a strong indication that the $\omega-$exchange is the main mechanism for the considered process and that the Roper resonance is excited in this process.

V. CONCLUSIONS

Some of the recent results obtained in the study of the deuteron structure have been reviewed. Despite the large precision and the new region of internal momentum explored, questions arised many decades ago are still actual:

- The relative role of different possible components in the deuteron wave function: isobar configurations, six-quark components, etc..;
- The relativistic description of the deuteron structure: the number of independent components of the deuteron wave functions as well as the number and the nature of their arguments;
- The relative role of the different possible mechanisms in the simplest reactions with deuterons: for example the role of meson exchange current in the description of the electromagnetic form factors of the deuteron;
- The kinematical region corresponding to the transition regime in the deuteron structure: i.e. from the nucleon-meson picture of the deuteron to the quark-gluon description.

These problems are far from being solved. The experimental study of polarization phenomena remains the most fruitful way in this investigation. If, in the case of elastic ed-scattering we are near the limits of the experimental possibilities, in reactions such as the deuteron photodisintegration, $\gamma+d\to n+p$ or the coherent pion photoproduction on on the deuteron $\gamma+d\to d+\pi^0$, a wide program of polarization experiments can be realized, due to the rich spin structure of the corresponding matrix elements. Moreover the experimental study of new reactions, such as the coherent neutral pion production on the deuteron, $e+d\to e+d+\pi^0$, in the near threshold region and in the Δ-region (for large momentum transfer) can bring useful information.

These conclusions apply to the hadronic sector, too. The complete experiment for the simplest case, the *dp* backward elastic scattering, requires further steps which can be realized in principle in the nearest future. The study of the nucleon resonances through reactions induced by isoscalar probes as deuterons and α particles seems to be very promising, in particular the polarization observables.

---

[1] L. C. Alexa *et al.*, Phys. Rev. Lett. **82**, 1379 (1999).
[2] D. Abbott *et al.*, Phys. Rev. Lett **82**, 1379 (1999).
[3] R.G. Arnold *et al.*, Phys. Rev. Lett. **35**, 776 (1975).
[4] D. Abbott *et al.* [JLAB t(20) Collaboration], Phys. Rev. Lett. **84**, 5053 (2000).
[5] M. P. Rekalo, E. Tomasi-Gustafsson and J. Arvieux, hep-ph/0003280
[6] J. Gunion and L. Stodolsky, Phys. Rev. C **51**, 427 (1995).
[7] V. Franco, Phys. Rev. D **8**, 826 (1973).
[8] V. N. Boitsov, L.A. Kondratyuk and V.B. Kopeliovich, Sov. J. Nucl. Phys **16**, 237 (1973)
[9] F. M. Lev, Sov. J. Nucl. Phys. **21**, 45 (1973)
[10] M. P. Rekalo, E. Tomasi-Gustafsson, and D. Prout, Phys. Rev. **C60**, 042202 (1999).
[11] V. Punjabi *et al.*, Phys. Lett. **B391**, 22 (1997).
[12] L. S. Azhgirei *et al.*, Phys. Lett. **B350**, 178 (1995).
[13] B. Kuehn *et al.* Phys. Lett. **B334**, 298 (1994).
[14] Contributions from A. Litvinenko and L. Zolin, this volume.
[15] S. Platchkov *et al.*, Nucl. Phys **A510**, 740 (1990).
[16] M. K. Jones et al. Phys. Rev. Lett. **84**, 1398 (2000).
[17] A. Akhiezer and M. P. Rekalo, Dokl. Akad. Nauk USSR, **180**, 1081 (1968) and Sov. J. Part. Nucl. **3**, 277 (1974).
[18] R.G. Arnold, C. E. Carlson and F. Gross *et al.*, Phys. Rev. **C35**, 1426 (1980).
[19] V. Jankus, Phys. Rev. **102**, 1586 (1956).
[20] M. Gari and W. Krümpelmann, Phys. Lett., **B 274**, 159 (1992).
[21] S. Galster, H. Klein, J. Moritz, K. H. Schmidt, D. Wegener and J. Bleckwenn, Nucl. Phys. **B32**, 221 (1971).
[22] D. Rohe *et al.* Phys. Rev. Lett. **83**, 4257 (1999).
[23] V. V. Burov, V. N. Dostovalov and S. E. Suskov, Sov. J. Part. Nucl. **23**, 317 (1992).
[24] R. Adler and S. Drell, Phys. Rev. Lett. **13**, 349 (1964);
M. Chemtob, E. Moniz and M. Rho, Phys. Rev. **C10**, 344 (1974) and refs. herein.
[25] J.W. Van Orden, N. Devine and F. Gross, Phys. Rev. Lett. **75**, 4369 (1995).
[26] R. Madey, *The electric form factor of the neutron from the* $d(\vec{e},e'\vec{n})p$ *reaction*, JLAb Proposal PR-93-038;
D. Day, *The Charge Form Factor of the Neutron*, JLAb Proposal E-93-026
[27] T. Baker et al. Phys. Rep. (1997) and refs. herein.
[28] H. P. Morsch *et al.*, Phys. Rev. Lett. **69**, 1336 (1992).
[29] L. D. Roper, Phys. Rev. Lett., **12**, 340 (1964).
[30] M. P. Rekalo and E. Tomasi-Gustafsson, Phys. Rev. C **54**, 3125 (1996);
E. Tomasi-Gustafsson, M. P. Rekalo, R. Bijker, A. Leviatan and F. Iachello, Phys. Rev. C. **59** (1999) 1526.
[31] R. Bijker, F. Iachello and A. Leviatan, Ann. Phys. (N.Y.) **236**, 69 (1994);
R. Bijker, F. Iachello and A. Leviatan, Phys. Rev. C **54**, 1935 (1996);
R. Bijker, F. Iachello and A. Leviatan, Phys. Rev. D **55**, 2862 (1997).
[32] P.L. Chung et al., Phys. Rev. C **37**, 2000 (1988).
[33] Exp. LNS250 (unpublished).
[34] L.S. Azghirey et al., Phys. Lett. B **361**, 21 (1995);
L.S. Azghirey et al., Phys. Lett. B **387**, 37 (1996);
L.S. Azghirey et al., JINR Rapid Communications No. 2[88]-98.
[35] M. E. Schulze *et al.*, Phys. Rev. Lett. **52**, 597 (1984);
R. Gilman *et al.* Phys. Rev. Lett. **65**, 1733 (1990);
I. The *et al.*, Phys. Rev. Lett. **67**, 1773 (1991);

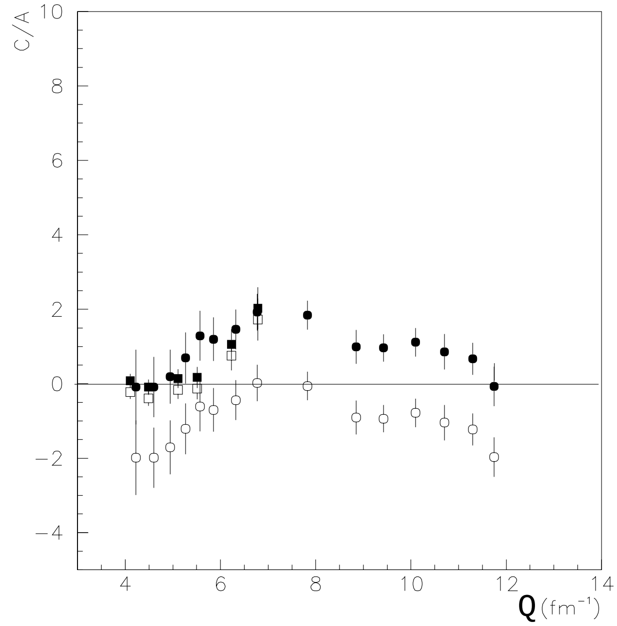

FIG. 1. Ratio C/A for the two sets of data, as a function of Q (fm^{-1}): squares from [2]; circles from [1], corresponding solid symbols after renormalization (see text)

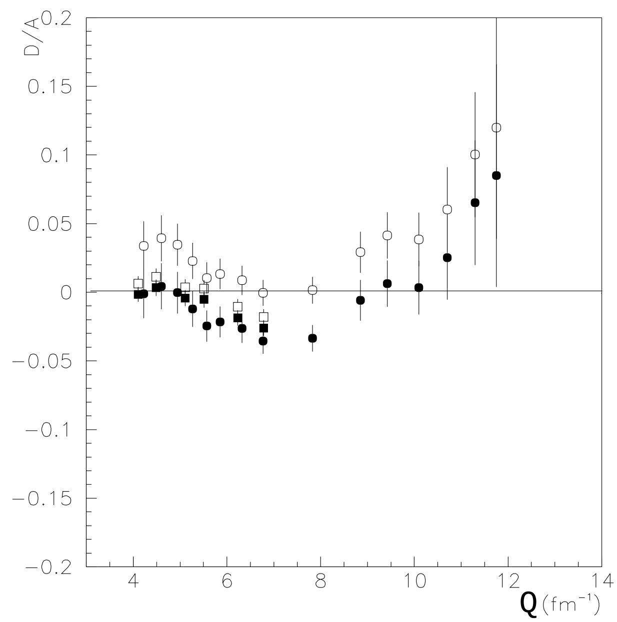

FIG. 2. Ratio D/A for the two sets of data, as a function of Q (fm^{-1}): squares from [2]; circles from [1], corresponding solid symbols after renormalization (see text)

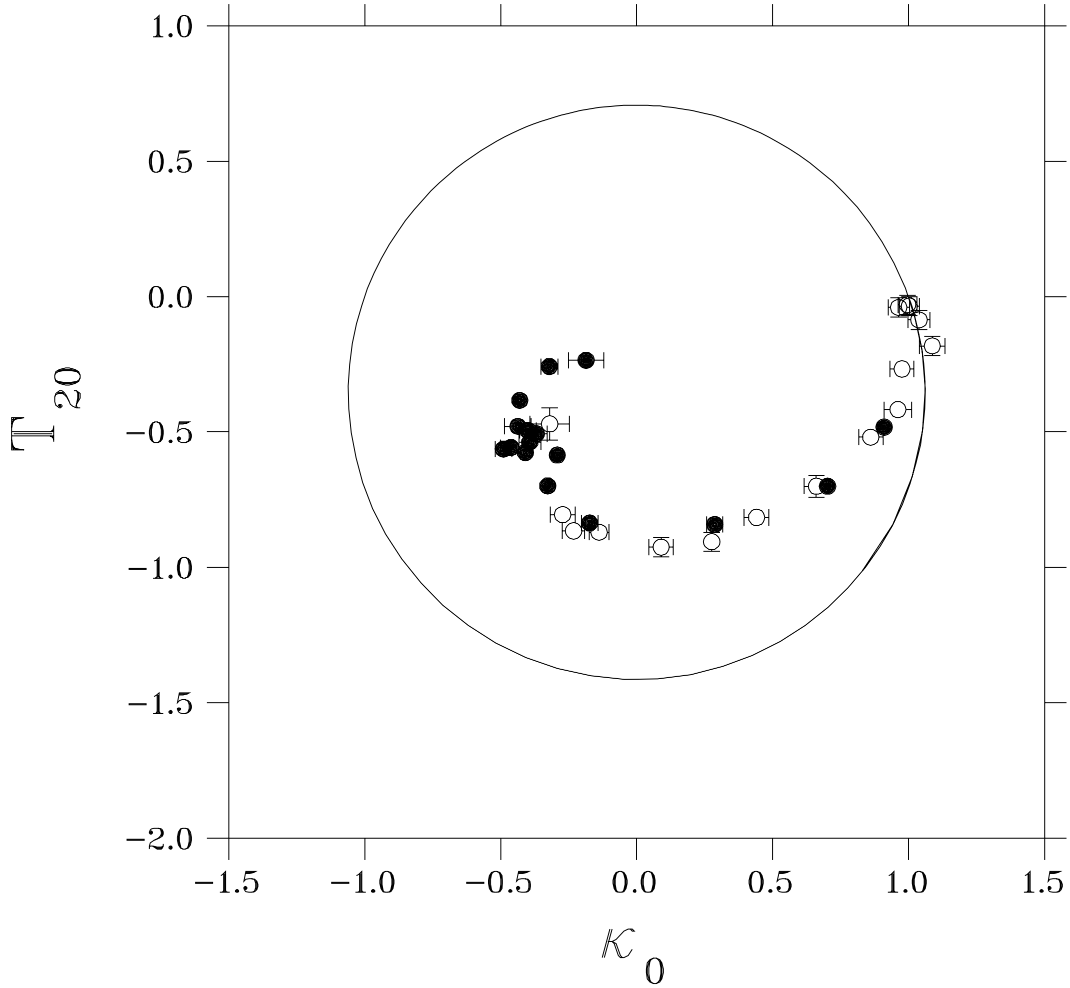

FIG. 3. Tensor analyzing power versus polarization transfer coefficient for *dp* backward elastic (filled circles) and for inclusive break-up (open circles). The solid curve is the IA prediction.

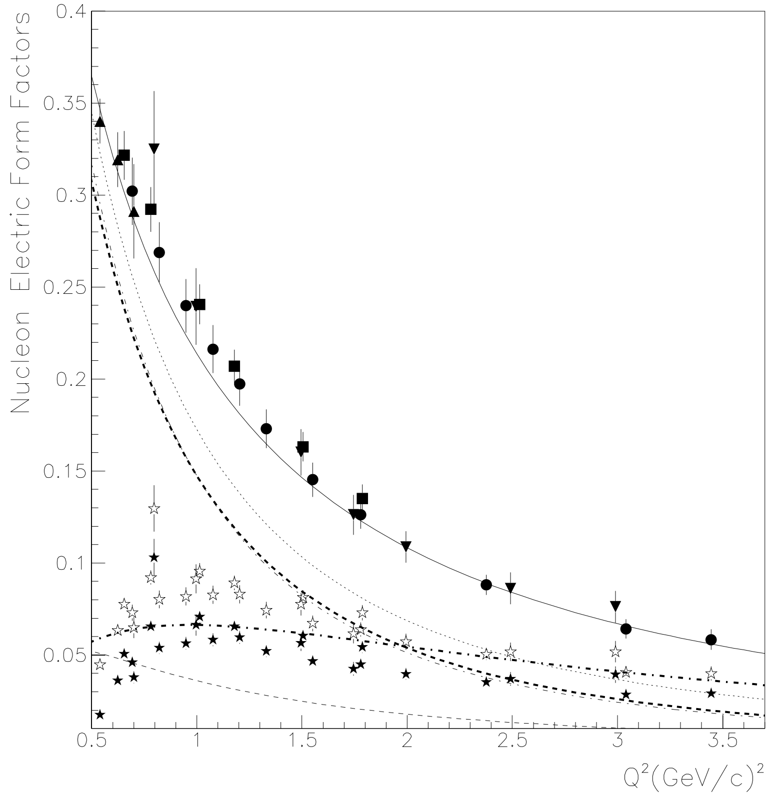

FIG. 4. Nucleon electric form factors as functions of the momentum transfer Q^2. in the framework of IA with Paris potential. The isoscalar electric form factor is derived from the deuteron elastic scattering data: [15] (solid triangles), [1] (solid circles), [2] (solid squares), and [3] (solid reversed triangles). The electric neutron form factor is shown as solid stars when calculated from the dipole representation of G_{Ep} (dotted line) and open stars when Eq. (5) is taken for G_{Ep} (thin dashed-dotted line). The parametrization [20] is shown for G_{Es}(solid line), for G_{En} (thick dashed-dotted line) and for G_{Ep} (thick dashed line). The thin dashed line is the parametrization [21] for G_{En}.

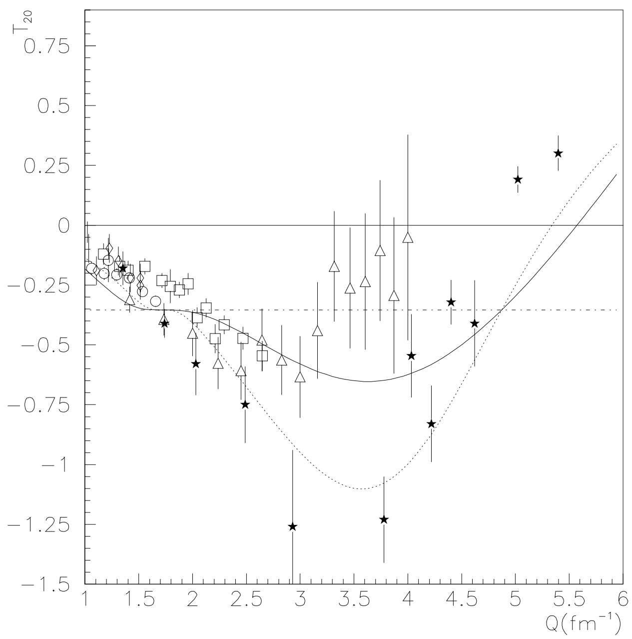

FIG. 5. Experimental data for T_{20} for $e^- + d \rightarrow e^- + d$ elastic scattering (filled stars) [35] and $d + p \rightarrow d + X$ at incident momenta of 3.75 GeV/c (open diamonds) [33], 5.5 GeV/c (open circles), 4.5 GeV/c (open squares), 9 GeV/c (open triangles) [34]. Prediction of the $\omega-$exchange model for $r = 0$ (dashed-dotted line). Calculations are shown for the case when only the Roper resonance is considered (dotted line) and for the case when all the four resonances (6) are considered (solid line).